Beyond Mini-Splits

An Introduction to Variable Capacity Equipment for Whole-House HVAC Designs

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Agenda

Preview
Perspective
Part-Load
VRF
Disclaimer

The mention of any product, service or information does not constitute an endorsement, nor implied endorsement. None of these companies are supporting this seminar.
What is VRF?

• Established heating & cooling technology for commercial and residential applications.
• Provides for variable capacity operation.
VRF Multi-Split Technology
VRF Multi-Split Technology
VRF Multi-Split Technology
VRF Vendors & Industry Dynamism

- Mitsubishi
- Daikin
- Sanyo
- Fujitsu
- LG
- Gree
- McQuay
- Johnson Controls

- Carrier
- Rheem/Ruud
- Frigidaire
- Trane
- Lennox
- Goodman
- Toshiba
- Samsung
VRF Market Penetration
Perspective
50 Years

1803

1853
50 Years

1903

1953
50 Years

1955

Positive Energy

2055
HVAC Looking Forward...

- Desiccant based evaporative cooling (Especially Liquid Desiccants)
- Thermo-electric heating and cooling
- Quantum Effect devices
Changing Performance
Enhanced functionality. Superior performance.

Not for free
• Highly engineered systems
• Specialized materials
• Complex assemblies
• Precise tolerances
Changing Client Dynamics
Feedback Loop

Improved Product Performance

Increased Consumer Expectations
The New Normal

- High Performance
  - Comfort
  - Health
  - Safety
  - Durability
  - Energy Efficiency

- Improved Product Performance
- Increased Consumer Expectations
Control Layers & Equipment Loads
One Functional System

What do we want this system to do?

What should it deliver?

- Comfort
- Durability
- Health
- Safety
- Energy Efficiency
Control Strategy

Control flows across a boundary:

• Heat
• Air
• Moisture
Control Layers

Priority Order:
1. Bulk Water  
   (Rain & Ground, Liquid)
1. Air
2. Water Vapor
3. Thermal

Building Envelope Assembly (Boundary)
Control Layer Failure

Keep Outside Out & Inside In. Control Exchange.
Control layer failure - All 3 Required

1. Something to leak
2. Opening
3. Driving force
Control Layers are Imperfect

Range of Human Body Temperature
- 99°F
- 97°F

Range of Acceptable Indoor Temperature
- 78°F
- 68°F

Range of Outdoor Temperature
- 120°F
- 20°F

Cooling need
Leaking control layers leads to heating and cooling loads

Heating need
Daily, Hourly Load Variations

System 2 - Hourly Room Net Gain

Note: Glass gain as a percent of net gain is shown in parenthesis. Although floor, roof, wall and door gains also vary throughout the day, for this graph and in Manual J glass gains are the only ones that fluctuate.
Typical Indoor Weather Pattern

The graph shows the indoor relative humidity (RH) and dry bulb temperature (DP) over a period from 8/20/13 to 8/22/13. The RH (%) line is represented by a red line, and the DP (deg F) line is represented by a green line. The data points are marked with specific timestamps, including 19:12, 0:00, 4:48, 9:36, 14:24, 19:12, and 0:00 on 8/21/13. The graph indicates fluctuations in both RH and DP over time.
Changing Energy Codes

Moisture tolerance and resiliency following similar trend?
Changing Building Envelopes
Control Layer Products
There’s something happening here
What it is, is very clear
Control & Kaos?
Load & Part Load

Fixed Capacity & Variable Capacity
Load & Capacity

Load

Capacity
3 Types of People

1. Those who can do math
2. and those who can’t.
3 Types of Loads

- Extreme Load
- Design Load
- Part Load
Variable Loads
Austin Climate

Average Temperature Range
Austin City, Texas

Fahrenheit

1971-2000

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<th>Month</th>
<th>High</th>
<th>Low</th>
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<td>Dec</td>
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- High
- Low

rssWeather.com
Austin Climate
Atlanta Climate

PSYCHROMETRIC CHART
Atlanta, Georgia USA

Atlanta
CDH74 16803
HDD63 3025

73°F

115 Grains
Part Load Hours

Source: HTS Engineering
No Cooling. No Dehu.
Fixed Capacity

Single Speed

0% OFF

100% ON

Dot represents Equipment Operating Point & Percentage of Rated Capacity Delivered to Load (idealized)

Majority of US Market
Dual Capacity

Dual Stage & Unloaders

0% 50% 100%

OFF ON

0% 67% 100%
Variable Capacity

Inverter Scroll Compressor

0%  4-15%  100%
3 Types of Capacity

- **Single Speed**
  - Range: 0% to 100%

- **Dual Stage & Unloaders**
  - Range: 0%, 50%, 100%

- **Variable Capacity**
  - Range: 0%, 4-15%, 100%
VRF & Industry Performance Metrics
AHRI 1230-2010

- Full Load
  - EER
  - COP @47F
  - COP @17F

- Part Load
  - IEER
  - Heat Recovery
  - SCHE
Performance Metrics

Rated at Full Capacity Conditions

• **EER** – Energy Efficiency Rating = Btuh’s per Watt

• **SEER** – Seasonally adjusted; per AHRI formula

• **HSPF** – Heating Seasonal Performance Factor

• **COP** – Coefficient of Performance = In North America, typically rated for Heat Pumps at 17 & 47 degrees Fahrenheit.
Performance Metrics

Rated at Part-Load capacities (25%, 50%, 75% & 100%)

• **IEER** – Integrated Energy Efficiency Rating; Took the place of IPLV

• **SCHE** – Simultaneous Cooling & Heating Efficiency

Efficiency of Heat Recovery at simultaneous 50% heating & 50% cooling
IEER

IEER = (0.020 \cdot A) + (0.617 \cdot B) + (0.238 \cdot C) + (0.125 \cdot D)

Where:
A = EER at 100% net capacity at AHRI standard rating conditions
B = EER at 75% net capacity and reduced ambient (see Table 11)
C = EER at 50% net capacity and reduced ambient (see Table 11)
D = EER at 25% net capacity and reduced ambient (see Table 11)

(IPLV@0.1, 0.5, 0.3, 0.1)
Part load metrics only apply to equipment with capacities > 65kBtuh
VRF HVAC Technologies
VRF Technology
VRF Technology
Outdoor Condensing Units

S-Series
3-5 Tons
1Φ
14x38x54

R2, Y, H2iY
6-24 (30) Tons
3 Φ
30x48x65

WR2, WY,
6-24 (30) Tons
3 Φ
21x34x43
## VRF Outdoor Units

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Lennox</th>
<th>Mitsubishi</th>
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<tr>
<td>Model Number</td>
<td>XP25-036</td>
<td>PUMY-P36</td>
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<tr>
<td>Cooling Cap (kBtuh)</td>
<td>35.2</td>
<td>36</td>
</tr>
<tr>
<td>Heating Cap (kBtuh)</td>
<td>31</td>
<td>40</td>
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<tr>
<td>Pwr Htg (kW)</td>
<td></td>
<td>2.93</td>
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<tr>
<td>Pwr Clg (W)</td>
<td></td>
<td>3.22</td>
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<tr>
<td>Current Clg (A)</td>
<td>LRA 18, RLA 14</td>
<td>15.2</td>
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<tr>
<td>Current Htg (A)</td>
<td></td>
<td>12.9</td>
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<tr>
<td>Dims (WxDxH)</td>
<td>30x39x36 (48)</td>
<td>13x38x54</td>
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<tr>
<td>Weight (Lbs)</td>
<td></td>
<td>287</td>
</tr>
<tr>
<td>Sound P (dB(A))</td>
<td>58/73 (min/max)</td>
<td>49/51 (min/max)</td>
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Indoor Units

- Space Mounted
- Ceiling Recessed
- Concealed Ducted
Space Mounted

Wall Mounted
6-30kBtuh

Ceiling Suspended
15-36kBtuh

Floor Standing
6-24kBtuh
Wall Units

Trane 4MYW6  9-22 kBtuh

Fujitsu Halcyon ASUxxRLF  7-24 kBtuh

Gree GWCxx  9-36 kBtuh
Floor Standing

LG ARNUxxxCE  7.5-24.2 kBtuh

Mitsubishi PFFY-PxxNEMU-E  6-24 kBtuh

Panasonic S-xxMR1U6  7-24 kBtuh
Floor Standing

Image Source: Mitsubishi Electronics
Space Mounted: Choices

[Images of various space-mounted cooling systems and LG Electronics' Art Cool range]
Ceiling Recessed

4-Way Large Cassette
33”x33”, 12-36kBtuh

4-Way Small Cassette
22.5”x22.5”, 12-36kBtuh

One Way Cassette
16”x32”, 6-15kBtuh
Concealed Ducted

- Low (0.2iwc)
- Medium (0.6iwc)
- High Static (0.8iwc)

6 - 96kBtuh
(1/2 to 8 Tons)
VRF Multi-Split Air Handlers

- Panasonic S-xxMM1U6  0.7-18 kBtuh
- Daikin FXMQxxPVJU  0.6-4.0 kBtuh
- Carrier/Toshiba MMD4  2.5-4.0 kBtuh
Vertical Ducted

Vertical (Up or Down Flow) & Horizontal Left Air Handler
0.3, 0.5, 0.8 iwc, 12-54kBtuh
## Vertical (Horizontal) Air Handlers

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<thead>
<tr>
<th>Manufacturer</th>
<th>LG</th>
<th>Mitsubishi</th>
<th>DAIKIN</th>
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<tr>
<td>Model Number</td>
<td>ARNU183NJA2</td>
<td>PVFY-P18E00A</td>
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<tr>
<td>Cooling Cap (kBtu/h)</td>
<td>18</td>
<td>18</td>
<td>18</td>
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<tr>
<td>Heating Cap (kBtu/h)</td>
<td>20</td>
<td>20</td>
<td>20</td>
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<tr>
<td>Pwr Htg (W)</td>
<td>0.08</td>
<td>0.18</td>
<td>0.21</td>
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<tr>
<td>Pwr Clg (W)</td>
<td>0.08</td>
<td>0.18</td>
<td>0.21</td>
</tr>
<tr>
<td>Current Clg (A)</td>
<td>0.36</td>
<td>1.22</td>
<td>1.6</td>
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<tr>
<td>Current Htg (A)</td>
<td>0.36</td>
<td>1.22</td>
<td>1.6</td>
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<tr>
<td>Dims (WxDxH)</td>
<td>18 x 21.3 x 48.6</td>
<td>17-3/4 x 21 x 42-3/4</td>
<td>39-3/8 x 27-1/2 x 11-3/4</td>
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<tr>
<td>Weight (Lbs)</td>
<td>117</td>
<td>98</td>
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<td>Sound P (dB(A))</td>
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<td>CFM (L-M-H)</td>
<td>380/480/530</td>
<td>402/485/520</td>
<td>529/582/635</td>
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<td>0.3, 0.5</td>
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<td>0.2, 0.8</td>
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Branch Boxes, Splitters & Joints

![Image of branch boxes, splitters, and joints.](image-url)
VRF: Other Parts

Filter Chassis

Piping Headers & Joints

PC Connection
Concealed Ducted
Concealed Ducted

Concealed Ducted
VRF and Existing Buildings

- Less intrusive to existing architecture
- Small refrigerant piping instead of large ductwork
- Outdoor installation flexibility
How?
Variable Refrigerant Flow
Variable Refrigerant Flow

Linear Electronic Expansion Valve (LEV)
• LEV opens & closes a precise amount w/ each control pulse to its windings
• Thousands of pulses per full open/close
• Precision microprocessor based control
Variable Refrigerant Flow
Inverter Drive

Inverter Circuit: Variable Frequency & Voltage Output

60Hz VAC In

Variable Capacity

15 – 125 Hz VAC Out
Inverter Circuit: Step 1

AC $\rightarrow$ DC
Inverter Circuit: Step 2

DC \rightarrow AC
DC to AC on Demand

Fixed Input Power Frequency 60Hz

Variable Frequency Output to Compressor Motor

Inverter

AC/DC Rectifier

DC/AC Inverter

Control signal

60 Hz

115 to 15 Hz
Inverter Scroll Compressor

- 30 to 40% Efficiency Improvement
- Soft-starts with no electrical inrush
- Longer life due to soft-starts
Inverter Drive

15 Hz
Low Part Load

125 Hz
Peak Load
Conventional Comfort

Image Source: Mitsubishi Electronics
**VRF Comfort**

- **Room Temperature**
  - Very fast!
  - Room temperature is steady.
  - Comfortable!

- **Set Temp.**
  - High rotation speed up to 100-125Hz generates accelerated performance!
  - 150Hz
  - 60Hz
  - 30Hz
  - 0Hz

- **Compressor**
  - Starting current at low level
  - Keep rotation speed low after temperature is stabilized.
  - Very efficient!

*Image Source: Mitsubishi Electronics*
Compressor Motor Current
Compressor Motor Current
### Operating Currents

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<th>Indoor Unit (A)</th>
<th>Outdoor Unit (A)</th>
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<td>Conventional</td>
<td>3 - 12</td>
<td>20 - 100</td>
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<tr>
<td>VRFZ</td>
<td>0.15 - 6</td>
<td>2 - 25</td>
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Recap: Inverter Benefits

– Precise control & stability of indoor conditions
– Low starting currents
– Long run times
– Reduces compressor cycling
– Improved durability/longevity
– Variable capacity operation
– Rapid ramp up to meet load
– Minimum capacity to as low as 4% of rated
VRF Space Savings
Space Required to Deliver 20 tons of Cooling

Rectangular Ductwork (DX System) 40” x 20”

Round Ductwork (DX System) 30” Round

Piping (4 Pipe System) 3” CHWS&R, 3” HWS&R

Piping (VRF) 1³⁄₄” Gas 1 ¹⁄₈” Liquid
Quiet Operation

Image Source: Mitsubishi Electronics
VRF & Energy Modeling

• Energy Plus
• EnergyPro
• Others using DOE2.1 engine
VRF, Inverter-Drive & Beyond
Pricing Comparison

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<th>k$/Ton</th>
<th>$1.5</th>
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*GSHP pricing does not include 30% Federal tax credit
Summary
VRF Benefits

- Efficient part-load performance
- Versatility
- Comfort/control
- Multiple independent indoor zones
- Quiet operation
- Improved latent control & filtration w/ longer run times
- Reduced need for ductwork & associated duct losses/impacts
- Easy of installation
- Many units are ventilation compatible
- High reliability/low maintenance
VRF Issues & Concerns

- Market Inertia
- Lack of 3rd party performance data
- Inappropriate industry rating metrics
- Cost
- Installer/Service training & skills
- Complexity
- Power sensitivity
- Supplemental heating integration
- Filtration concerns
- Costly to service/cleaning condenser coils
- Lack of control based on latent (most units)
- Need for supplement dehumidification at low loads
Thank You